Accelerator Physics Update

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VLHC Magnet Technologies Workshop

Fermilab, May 24, 2000

Update since last Magnet Technologies Meeting….

- Lake Geneva Workshop
  - Feb 1999 at Lake Geneva, WI
  - “VLHC Workshop on Accelerator Physics”

- US/LHC Accelerator Physics Workshop
  - Feb 2000 at BNL --
  - “Accelerator Physics Experiments for Future Hadron Colliders”

- Future meeting --

$\Rightarrow$ VLHC sponsored workshop in the fall;
to concentrate on beam physics experiments

A List of Issues for VLHC...

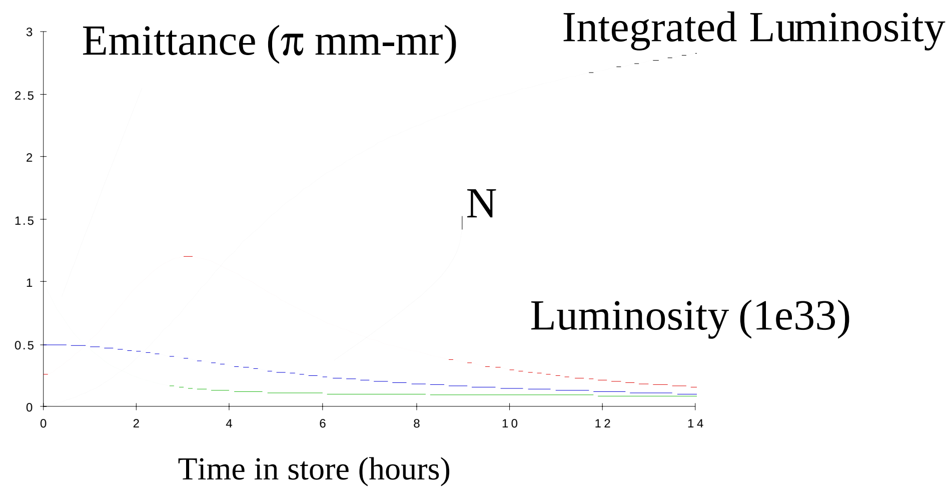
- Magnet Aperture
- Lattice Design
- Synchrotron Radiation
- Instabilities/feedback
- Longitudinal Parameters
- Beam-beam Effects
- Emittance Evolution/Control
- Energy Deposition

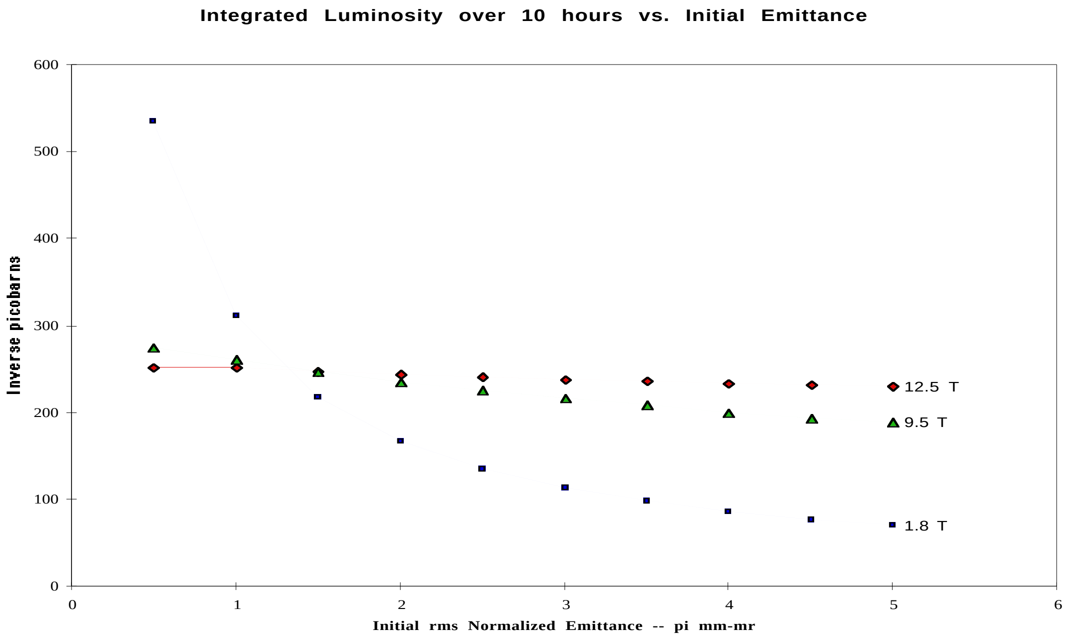
At 50 TeV, mostly just gets a bit harder...

- Synchrotron radiated power into magnets
- Stored beam energy
- Instability thresholds
- Ground motion sensitivity (motion amplitude vs. beam size)
- Etc…

… but, some possible advantages,
especially for high field options:

- Luminosity enhancement
- Simplified IR designs
- Integrated luminosity vs. initial emittances


Emittance (π mm-mr)
Integrated Luminosity
N
Luminosity (1e33)
Time in store (hours)


Integrated Luminosity over 10 hours vs. Initial Emittance
Inverse picobarns
12.5 T
9.5 T
1.8 T
Initial rms Normalized Emittance -- pi mm-mr

Lattice Design

Rings:

Arcs + IR/UT modules; dispersion suppressors

- all lengths in units of bunch spacing
- IR/UT/DS lengths multiples of half cell length

Arcs:

standard FODO cells

- standard magnets; if necessary, occasional short dipoles with space left for cryo-equipment, power feeds, etc.
- dispersion suppressors at ends of arcs

warm/free space

- Added later at SSC, to provide space for future upgrades (power/feed points, dampers, instrumentation, spin devices, etc., ??)

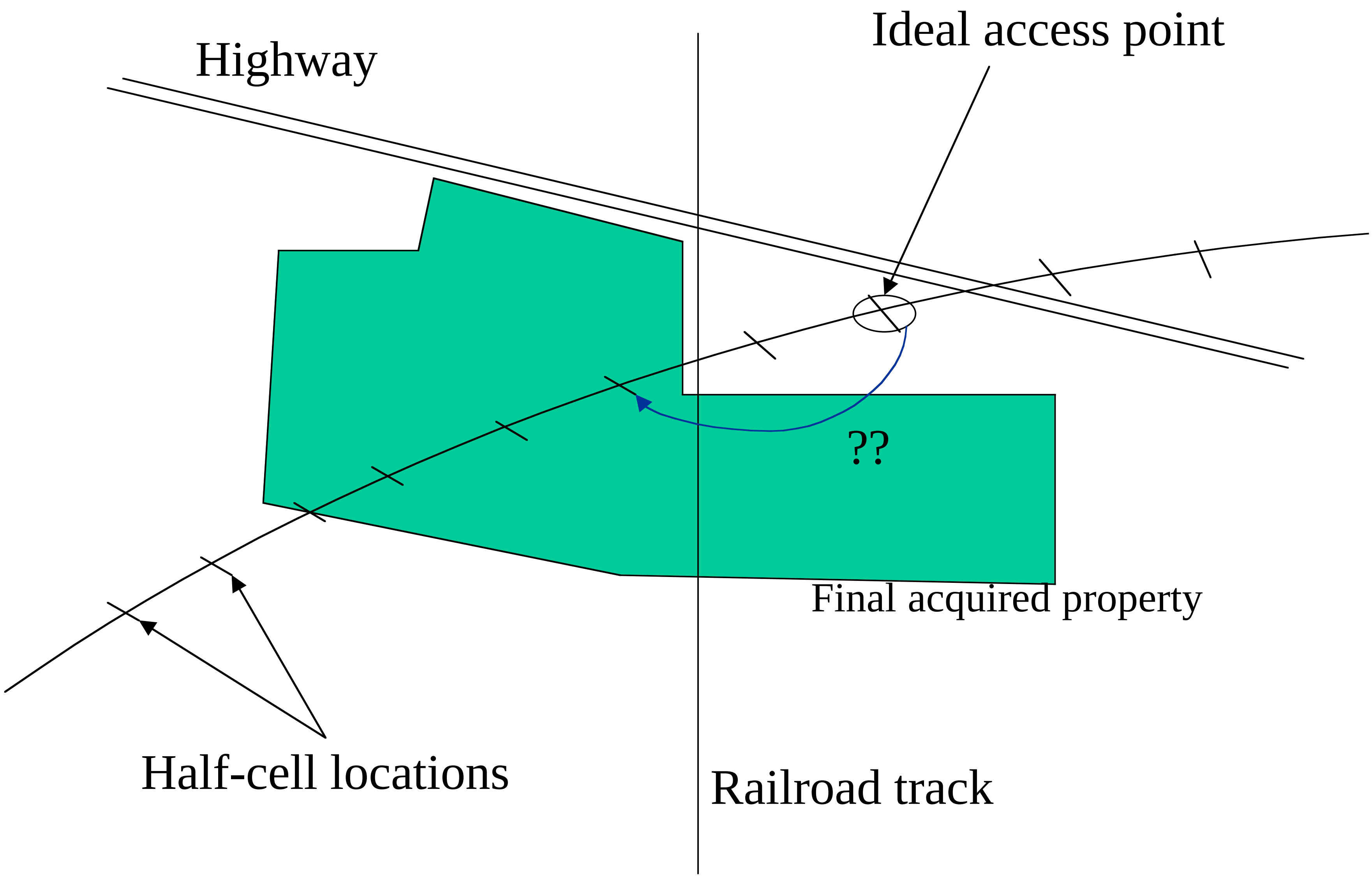
*** ***modularity*** ***

Utility Regions:

- Injection, extraction, rf, instrumentation

Interaction Regions:

- Low beta, orbit/tune/chromaticity control, dispersion, crossing angle


Ideal access point
Highway
??
Final acquired property
Half-cell locations
Railroad track

Some Notes on Sparse Correctors

Look at having sparse corrector layout:

- Better packing fraction
- Shorter cable runs to correctors
- Fewer interfaces to power, cryo system

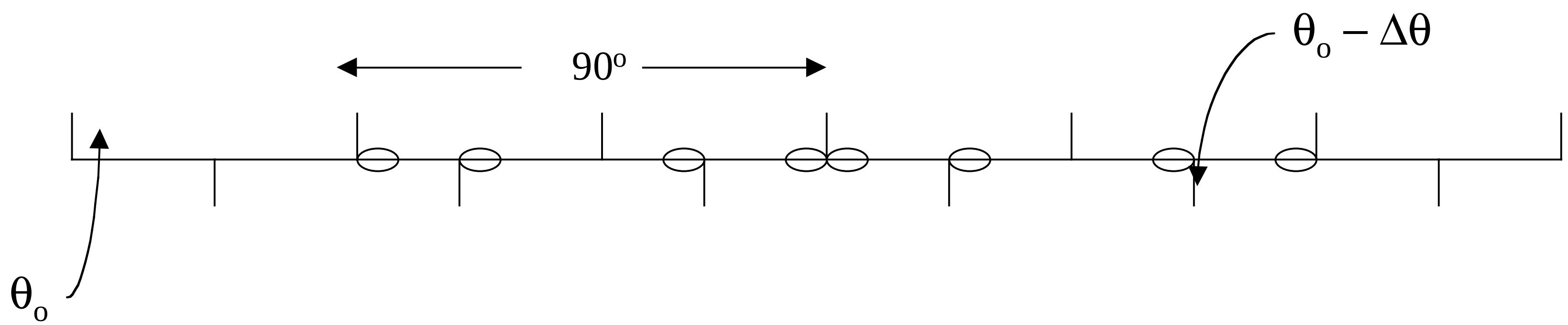
For now, study steering, tune, and chromaticity corrections …

Issues:

- Corrector strengths
- Lattice perturbations
- Allowable orbit distortions
- Dynamic Aperture (sextupoles)

Correction Region

Near each access point, try:



= "short" or "missing" magnet

Use space for tune, chromaticity, steering adjustments...

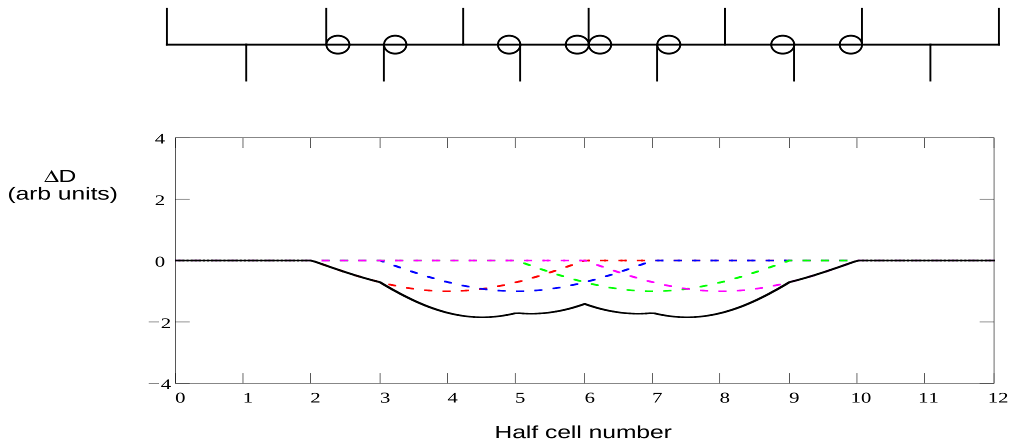
As a numerical example, take SSC numbers:

- $L_{sec} \approx 4$ km
- $L = 90$ m, $\mu = 90^o$
  - $D_{max} = (243\ \text{m})\theta_o$
  - $D_{min} = (116\ \text{m})\ \theta_o$
- Take $\Delta\theta/\theta_o = 1/5$

  (1/5 dipoles per half cell)

$\Rightarrow$ *Then….*

Disturbance of Dispersion Function:



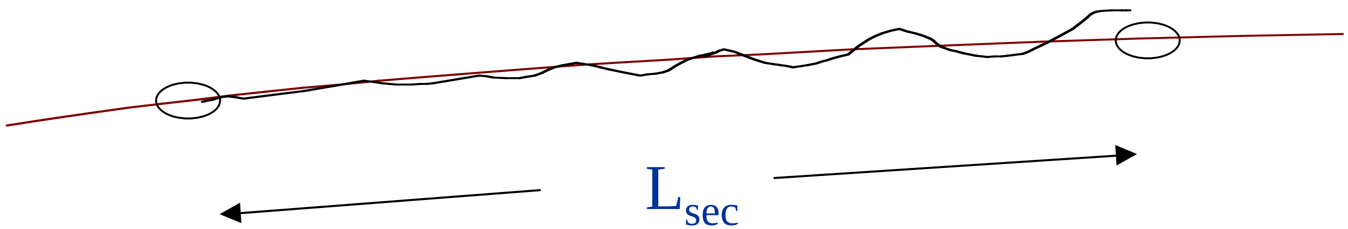
$\Delta\theta/\theta_o = 1/5$

(in SSC, 15 m)

<u>Location</u>	$\underline{\Delta D/D_0}$
2	0
3	-16
5	-25%
6	-15%
7	-25%
9	-16%
10	0

So, chromaticity correctors will need to be stronger by appropriate amounts...

Steering



for quad displacement d, $\Delta\theta = d/F$

so, at *n*-th quad,

$$\Delta x_n = \sum_i \theta_i \sqrt{\beta_i \beta_n} \sin \psi_{i \to n}$$

$$\langle \Delta x_n^2 \rangle = \theta_{rms}^2 \beta_n \langle \beta \sin^2 \psi_{i \to n} \rangle n$$

$$\Rightarrow \Delta x_n^{rms} = \theta_{rms} \sqrt{\langle \beta \rangle \beta_n} \sqrt{n/2}$$

So:

$$\boxed{\Delta x_n^{rms} = \frac{2 d_{rms}}{L} \sin \frac{\mu}{2} \sqrt{\langle \beta \rangle \beta_n} \sqrt{n/2}}$$

Future Steps...

- Shorten / Optimize module
  - * change half-cell length?
  - * abandon FODO?
  - * ???

- Practical range of tune adjustment
  - * beta-beat
  - * effect on chromaticity correction

- Range of steering corrections
  - * use of various steering algorithms
  - * tolerable residual orbits

- Dynamic Aperture with sparse chromaticity correction

- Effect on phases *between* modules

Magnet Aperture

Beam size vs. pipe size vs. coil diameter

- Cell length
- Phase advance
- Correctors
- Alignment

For phase advance

$$\mu = \sin^{-1}(L/2F) = 90^\circ$$

$$\hat{\beta} = 3.41\ L$$

$$\hat{D} = 2.71\frac{L^2}{R}$$

Where

L = half cell length, R = radius of curvature

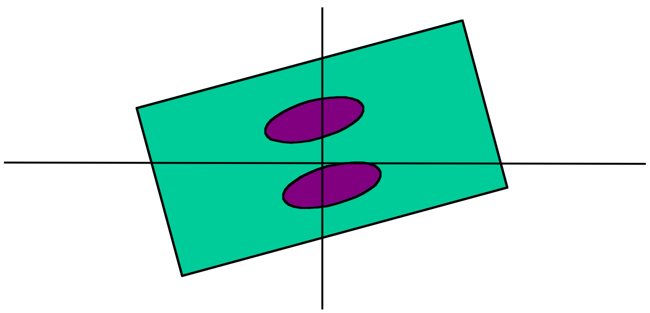
Tune shift due to systematic multipole, b_n:

δ = rel. momentum, ε = emittance

n	Tune shift, $\Delta\nu$
1	$\langle \beta b_1 \rangle /2$
2	$\langle b_2 \beta D \rangle \delta$
3	$3\langle b_3 \beta^2 \rangle \varepsilon/8 + 3\langle b_3 \beta D^2 \rangle \delta^2/2$
4	$3\langle b_4 \beta^2 D \rangle \varepsilon\delta/2 + 2\langle b_4 \beta D^3 \rangle \delta^3$

Alignment Issues

- Orbit control vs. cell length
  - Accuracy of local smoothing of magnet placement, etc.
- Local coupling and its effects
  - Quadrupole roll
- Ground Motion
  - Long term motion, re-alignment
- Alignment of “two rings” while using 2-in-1 magnets



Longitudinal Parameters

- Accelerating voltage (w/ or w/o Synch. Rad.)
- Choice of radio frequency and bunch length
- Longitudinal heating for IBS lifetime control,
  Landau damping, etc.

Instabilities and Cures

•resistive wall, head-tail, multibunch, etc.

➡ Beam pipe requirements: diameter, material, etc.

- ring-wide impedance budget and its control

  ➡ beam pipe AND rf cavities, BPM's, kickers, septa, magnet interconnects, etc.

- feedback and *feedforward* systems

  ➡ Low field -- resistive wall multibunch instability growth times (Snowmass) < *1 turn!*

  Presently, believe can cure this with feedback/forward system

Beam-beam Effects

- Head-on incoherent tune shift tolerance
  - ➡ Reduced with flat beams (high field?)

- H.O. tune shift compensation using electron beams?
  - ➡ test set-up at Fermilab (Shiltsev, et al.)

- Parasitic crossings
  - ➡ long range coherent tune shifts, compensation

Emittance Growth and Control

- injection errors
  - ➡ e.g., $\Delta x/\sigma_x$ = 1mm/0.5mm ---> 3x emitt. growth

- ground motion, power supply ripple, RF noise, etc.

- synchrotron radiation mitigates the deterioration of transverse emittance in the high field designs; how much *can* we tolerate at injection, though?

Energy Deposition

- Beam induced radiation effects
- Beam Abort Systems
- Beam Halo Scraping Systems

  ➡ Comparisons:

  Tevatron: 1 TeV x 2e13 = 0.003 GJ

  SSC: 20 TeV x 1e14 = 0.3 GJ

  LHC 7 TeV x 5e14 = 0.6 GJ

  VLHC (hi) 50 TeV x 1e14 = 0.9 GJ

  VLHC (low) 50 TeV x 1e15 = 9.0 GJ

- Interaction Region Element Protection

  ➡ power delivered into IR quads:

  50 TeV x 10^{34} $cm^{-2}sec^{-1}$ x 130 mbarn

  ➡ 10 kW *in each direction*

Instrumentation and Diagnostics

- Instruments to measure...
  - Beam positions
  - Tunes
  - Beta functions
  - Chromaticity
  - Transverse profiles
  - Bunch length
  - Etc...

- Data analysis and database issues

- Hardware reliability, radiation hardness, etc.

- Measurements usually to ~10% accuracy

  ➡ Do we need better? (likely YES!)
  ➡ Can we do better? (…..*????*)

Synchrotron Radiation

- Impacts on
  - cryo system
  - beam screen/liner
  - (and hence, magnet design…)

  - Low-field (Snowmass): 48 kW / (646 km * 0.8)
    = 0.09 W/m
  - Hi-field (Snowmass): 189 kW / (104 km * 0.8)
    = 2.3 W/m

- Enhancement of luminosity
  - high field option

Question: Can synchrotron radiation really help?

- Does SR at high field lessen the field quality requirements at injection?
- What is a viable magnet bore aperture, considering beam-screen requirements?
- Does SR simplify the IR optical design (doublets vs. triplets)

Future Directions...

- What is minimum beam pipe aperture (include beam screen) which can be tolerated?
- Can *sparse* corrector schemes be achieved?
- Can fault-tolerant correction schemes be achieved, improving reliability?
- Does SR at high field *truly* lessen the field quality requirements at injection?
- Need to look for new and innovative ideas…
  - 4-bore full-range magnet? (Gupta)
  - Low-field injector with high-field storage ring?? (Dugan)
  - ??????

Future experimental beam studies relevant to VLHC

A report on the February 2000 US-LHC Collaboration Meeting

on

Accelerator Physics Experiments for Future Hadron Colliders

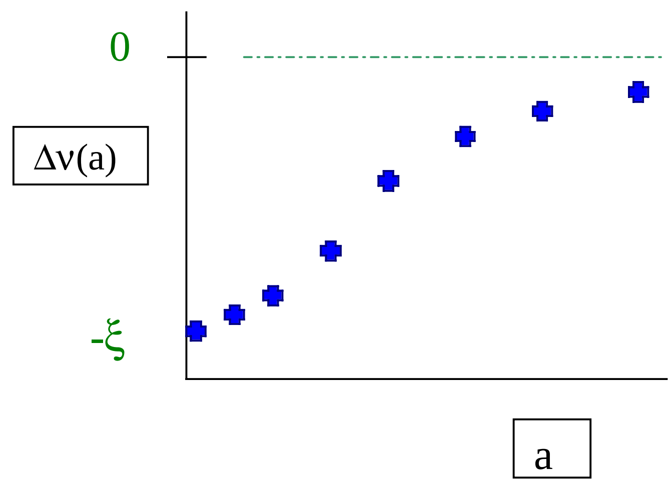
Major Areas of Discussion

- RHIC/Tevatron operation/studies plans
- IR corrections -- LHC and RHIC
- Beam-beam effects -- RHIC, Tev, LHC
- Persistent current effects -- HERAp
- Luminosity (bunch-by-bunch) optimization
- Detuning resonances via turn-by-turn data
- Broad band impedance measurements
- Local coupling correction
- AC dipoles, echos, …

POSSIBLE TOPICS FOR ORGANIZED EXPERIMENTS/STUDIES:

IR Corrections
IBS -- problem for studies, or study the problem…

Beam-beam tune footprint (HO and LR)
Beam-beam $\Delta\nu(a)$ -- á la E-778

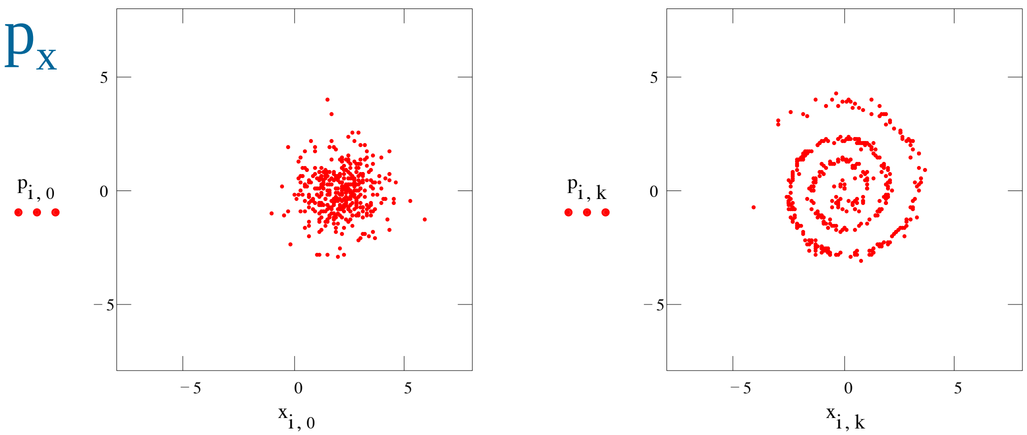


Crossing Angle Studies
 Lifetime
 Synchro-betatron resonances
 Dynamic Aperture

Bringing beams into collision
Coherent Beam-beam modes
 Observable?
 Feedback?

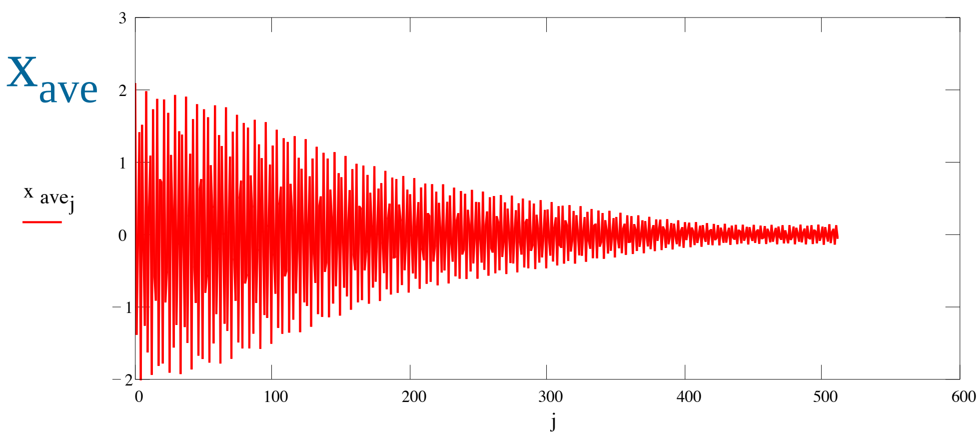
$\nu_0 = 20.618$ $\xi = 0.007$

$\Delta x = 2$



x

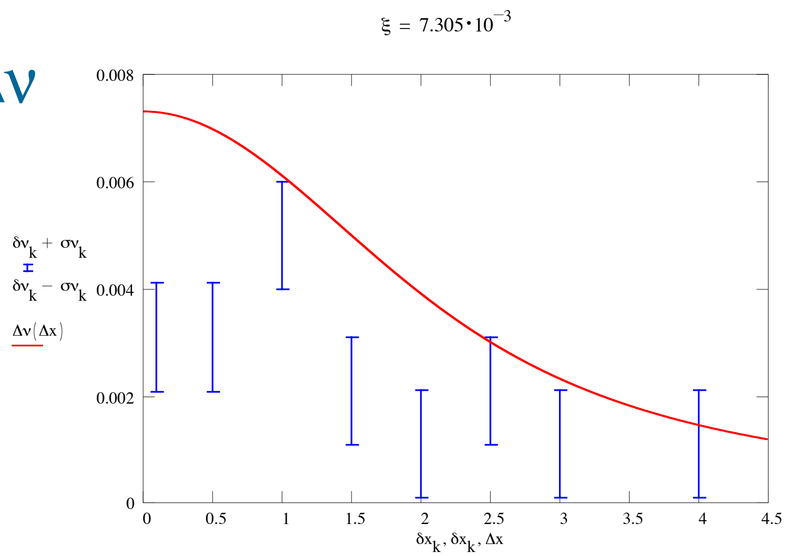
$$x_{ave_j} := \frac{1}{N_{part}} \cdot \left(\sum_i x_{i,j}\right)$$



Simulation:
induce a betatron oscillation of a low intensity, low emittance bunch interacting with a strong bunch (ξ = 0.007) at one interaction point...

Measure average bunch position vs. time (turns) and measure tune...

$\Delta\nu$

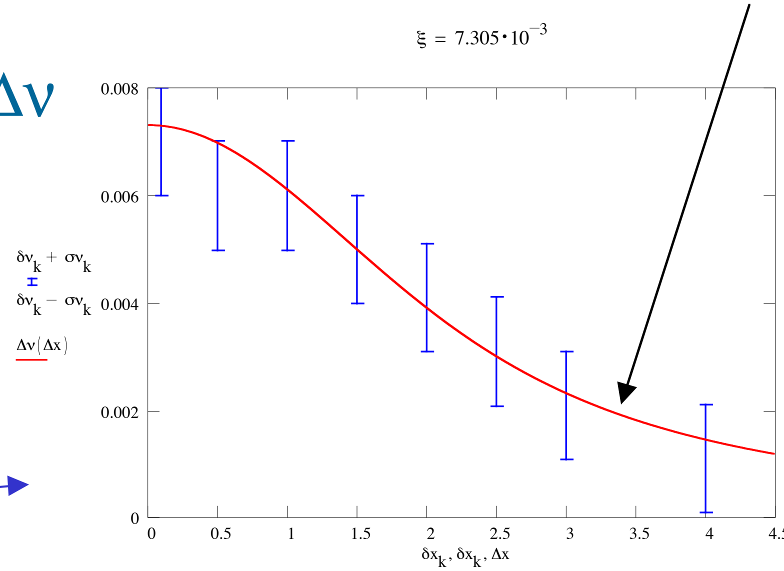


Strong beam emittance =

$6\pi\sigma^2\gamma/\beta = 20\ \pi$ mm-mr

Single particle prediction

$\Delta\nu$



Weak beam emittance

= $20\ \pi$ mm-mr

= $2\ \pi$ mm-mr

Kick ampl. (σ)

Next Steps… ...proposals to be generated:

- IR Corrections -- commissioning plan for IR correction system in RHIC
  - Setting of nonlinear correctors; future applications to LHC
- Beam-beam studies -- broad in scope; RHIC and Tevatron (HERAe/p?)
  - Beam-beam footprint measurements (Tevatron/RHIC)
  - Search for coherent π mode (predictions for RHIC)
- Collimation -- RHIC system; use to study IBS?
- Luminosity -- test LHC process at RHIC?
- AC Dipole -- install in RHIC, summer 2000; use as diagnostic tool to be explored

Fall Workshop...

- A workshop at/near Fermilab is to be organized for Fall 2000
- Hope is for strong proposals of above experiments (or others) for discussion
- Further topics to be explored…

to be announced soon on VLHC web page and via emails...